

15.2 A 13.56MHz RFID System based on Organic Transponders

E. Cantatore¹, T. C. T. Geuns¹, A. F. A. Gruijthuisen¹, G. H. Gelinck¹, S. Drews², D. M. de Leeuw¹

¹Philips Research, Eindhoven, The Netherlands

²Philips Semiconductors, Hamburg, Germany

Electronics based on organic transistors is suited to the manufacture of RFID tags for retail applications [1] because of its low-cost, mechanical flexibility and the possibility it offers to integrate circuits with antennas on packaged items. Organic electronics [2] and antennas can be manufactured using low-cost high-volume technologies like printing. Still a convincing demonstration of the technical feasibility of organic RFID transponders is missing.

The RFID tags presented here are manufactured using a photolithographic bottom gate technology [3] on a 25 μ m thick plastic substrate. The p-type semiconductor is pentacene, deposited from a precursor solution. Transistors consistently provide field-effect mobilities in the saturation region of 0.01cm²/Vs and on/off current ratios of 10⁵.

A crucial element in any DC-powered tag (Fig. 15.2.1) is the rectifier, the only device that must work at the RF carrier frequency. In our technology the organic semiconductor is the top layer in the stack. Integration of a vertical diode [4] would require additional masks and process steps; therefore we chose to implement the integrated rectifier using diode-connected transistors.

The channel length of the transistors is typically 4 μ m. As the mobility is 0.01cm²/Vs, one would expect a time of flight between source and drain of 160ns at a V_{ds} of 100V. Based on this simplistic estimation, a diode-connected transistor should operate correctly at the 125kHz RFID frequency but it should fail at 13.56MHz ($T=1/f \sim 74$ ns), the de-facto standard for item level identification.

When operating at 125kHz, one has to choose carefully between capacitive and inductive antenna coupling (Fig. 15.2.1). At low frequencies the antenna must have large inductance and a low DC resistance R_L to achieve a sufficient unloaded quality factor Q_L ($Q_L = \omega L / R_L$). To keep the antenna simple and cheap to manufacture, we preferred a capacitively coupled solution. Capacitive antennas can be produced with poorly conductive materials at low cost, but capacitive RFID systems lack the resonant tank on the tag and need close proximity between tag and reader to transfer to the tag a voltage sufficient to allow proper rectifier operation.

Two types of code generators were manufactured: the first produces a square wave (code A: ...101010...), the second a code that is easy to distinguish from a square wave (code B: ...101100...). Both tags use as rectifier two integrated diode-connected transistors (Fig. 15.2.1). The rectifier also acts as load modulator: the gate of the diode M1 is connected to GND or V_{dd} in synchronism with the code, modulating the current absorbed by the tag. Code A is generated with a ring oscillator, code B is generated with a three flip-flop counter clocked by an integrated ring oscillator. Flip-flops, inverters and NAND gates used in the design are reported in [5].

The tags were successfully energized and read out through the capacitive antenna using a 125kHz carrier. A photograph of the reader and the tag, showing a code B on the oscilloscope, is presented in Fig. 15.2.2. The carrier on the reader antenna has a peak-to-peak value of 110V, generating a tag supply of $V_{dd} = 25$ V. The data rate is 700b/s.

Once the feasibility of a RFID system based on organic transponders is demonstrated at 125kHz, it is important to build organic tags able to generate codes with enough information for practical

applications. Together with the code A and B tags we manufactured a tag with a 64b code generator. To optimize testability, the architecture shown in Fig. 15.2.3 was chosen. In this chip a 64b hardwired memory matrix is read out by enabling each column of the matrix, one after the other, and reading a row at a time within the enabled column. At power-up, the two barrel connected shift registers receive a reset. In this state, only one flip-flop per shift register is set and the first row and column are enabled. The data (1,1) is synchronized with the clock and passed to the Manchester encoder and to the modulator. Each subsequent clock acts on the row shift register (Fig. 15.2.3) and transfers the content of a new row within column 1 to the modulator. When a whole column is read, the following column is enabled and read out.

The 64b code generator proved fully functional. The correct output code was measured at a V_{dd} of ~ 30 V (Fig. 15.2.4). The data rate is 150b/s. A chip micrograph is shown in Fig. 15.2.7; the chip contains 1938 transistors. The 64b code generators were also measured with the integrated rectifier-modulator; the tags work in air with a V_{ACpp} voltage of 180V at 125kHz generating the Manchester code.

In order to establish the limits of our system, the functionality of the rectifier at higher carrier frequencies was characterized. The DC output voltage $-V_{dd}$ as a function of the input peak-to-peak AC voltage V_{ACpp} is shown in Fig. 15.2.5. The rectifier works at frequencies beyond 20MHz, far above the limits expected from the simplistic time of flight estimation. The reason for this excellent behavior is attributed to the fact that mobility in organic semiconductors is a power function of the applied gate-source voltage [6] and the rectifiers are operated at large V_{gs} .

A system capable of generating the 13.56MHz carrier and to read-out the tags via the capacitive antenna was built. This system could successfully energize and readout code A and code B tags at 13.56MHz. The measured output codes are shown in Fig. 15.2.6; the bit rate is 1kb/s for code A and 700b/s for code B. At this carrier frequency an inductive RF link could be advantageously used to increase the range of the RFID system.

Repeated exposure, in air, of the tags to the AC voltage needed to generate sufficient DC supply did not result in measurable performance degradation.

In summary, a complete RFID system has been presented working at 13.56MHz, the current standard for item level RF identification, which is able to distinguish between two tags manufactured with organic transistors. Also reported are functional organic 64b transponders. All measurements presented have been obtained in air. These results demonstrate the technical feasibility of commercially relevant RF identification systems based on organic tags.

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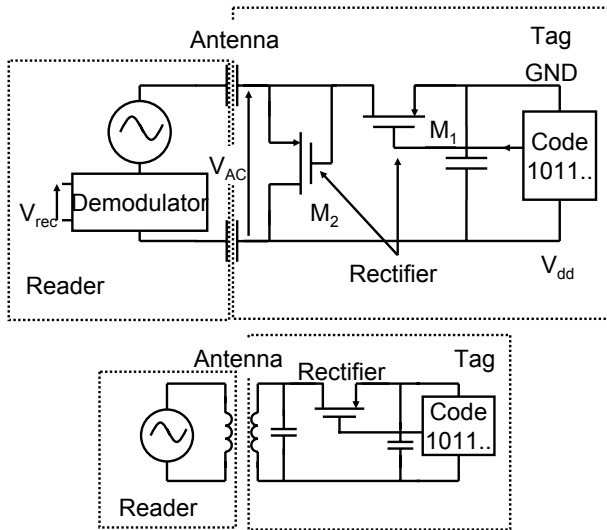


Figure 15.2.1: Capacitively and inductively coupled organic tags with integrated rectifiers.

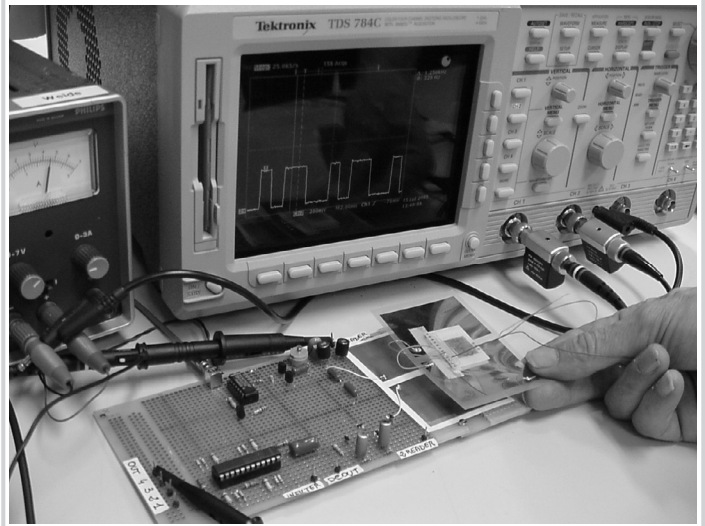


Figure 15.2.2: A code B tag is energized and readout at 125kHz using a base station and an oscilloscope.

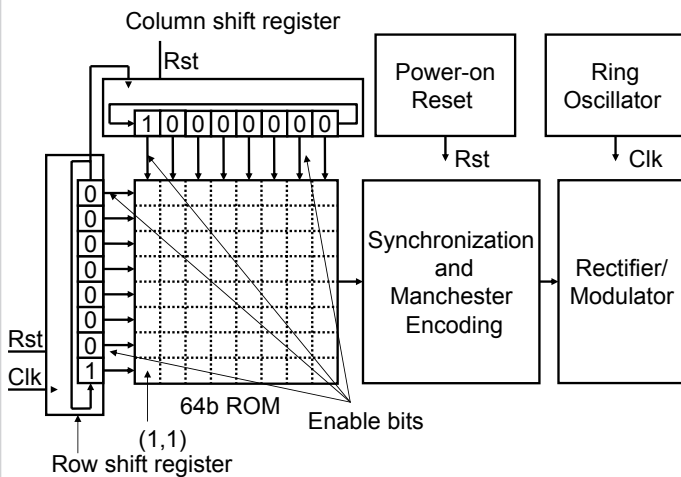


Figure 15.2.3: The 64b code generator architecture (reset state).

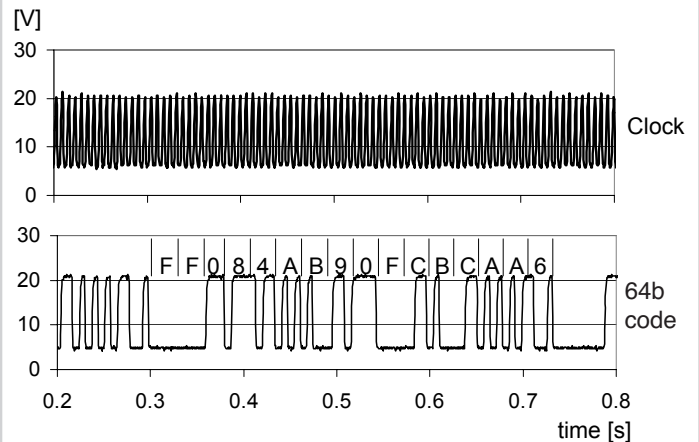


Figure 15.2.4: Signals measured on the 64b code generator at $V_{dd} = -30V$. The programmed code is shown in hexadecimal together with the generated code signal.

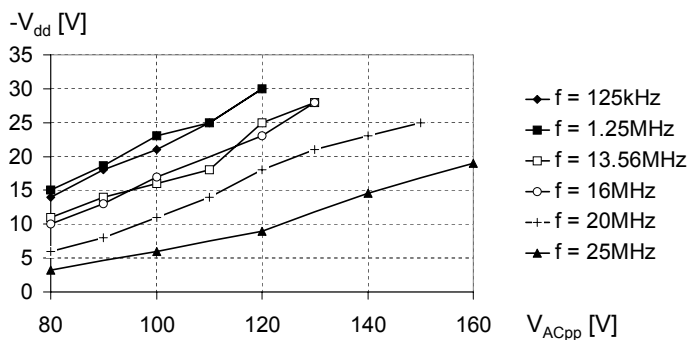


Figure 15.2.5: DC output voltage $-V_{dd}$ of the integrated organic rectifier as a function of the input peak-to-peak AC voltage V_{Acpp} at different frequencies.

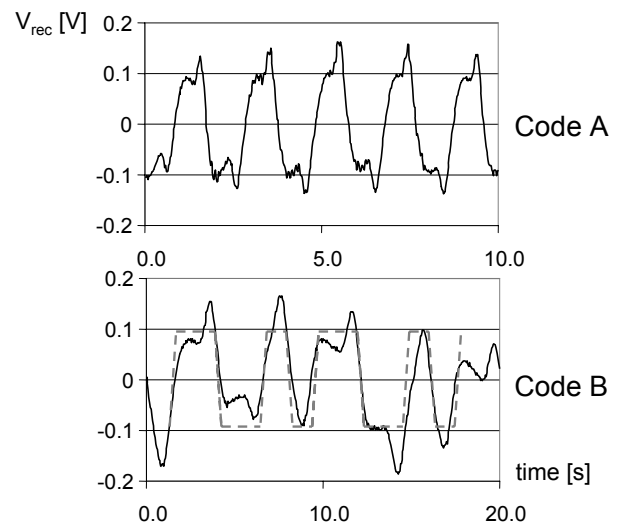


Figure 15.2.6: Output codes of a code A and a code B tag readout using a 13.56MHz carrier through a capacitive antenna.

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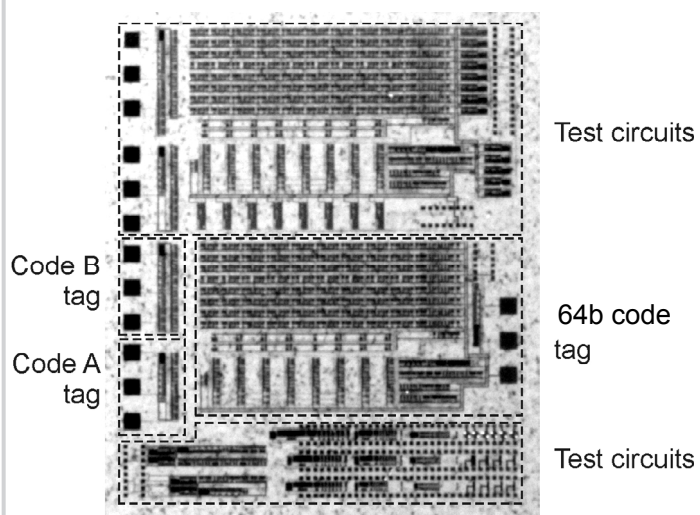


Figure 15.2.7: Micrograph of the reticle containing all organic tags.